Competency 1.3 **Radiation protection personnel shall demonstrate a working level knowledge of the various radiation detection, criticality and contamination monitoring systems and components.**

1. Supporting Knowledge and/or Skills

a. Discuss the operation and application of continuous air monitors (CAMs) and area radiation monitors (ARMs).

b. Discuss the operation and application of personnel monitors and process radiation monitors.

c. Discuss the operation and application of criticality monitors as related to radiation protection issues within the Department.

2. Summary

DOE 10 CFR 835, Occupational Radiation Protection, requires monitoring of individuals and areas under Subpart E - Monitoring in the Workplace. Section 835.401 offers several valid reasons why such monitoring must be performed. Among these are the:

- Documentation of radiological conditions in the workplace.
- Observation of changes in radiological conditions.
- Detection of a general buildup of radioactive material.
- Verification of the effectiveness of engineering and process controls.
- Identification and control of potential sources of personnel exposure to radiation and/or radioactive materials.

The DOE *Radiological Control Manual* offers detailed guidance for implementation of radiation protection in the DOE system. It establishes practices for the conduct of radiological control activities and states DOE's position and view on the best course of action currently available in the area of radiological controls. Chapter 5, Part 5 of the Manual discusses radiological monitoring and surveys.

NOTE: This manual is intended to be reissued in 1996 as a RadCon Technical Standard. The use of "shall" statements presently in the document will presumably be changed to "should" (or equivalent) statements. Regarding this radiation protection competency, statements referenced from the DOE *Radiological Control Manual* employing the word "shall" have been modified to "should" or similar wording to reflect the shift of this manual from a regulatory-based document to a guidance document.

DOE issued a series of implementation guides (IGs) covering a variety of radiation-related topics. The IGs are designed to provide acceptable methodologies that comply with 10 CFR 835. The implementation guide entitled, *Workplace Air Monitoring*, (G-10 CFR 835/E2- Rev. 1) offers detailed guidance in this topical area. For the purposes of this competency, information provided regarding CAMs is particularly relevant.

DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance,* describes the elements of an acceptable effluent monitoring and environmental surveillance program for DOE sites possessing radioactive materials. These elements are applicable to all DOE and contractor activities for which the DOE exercises environmental, safety, and health responsibilities and are intended to be applicable over the broad range of DOE facilities and sites.

The primary purpose of this regulatory guide is to specify the necessary elements for effluent monitoring and environmental surveillance of radioactive materials at DOE sites in order to comply with both applicable Federal regulations and DOE policy. The high-priority radiological effluent monitoring and environmental surveillance program elements contained in this document are given in the form of generic performance criteria, that is, the numeric limits and actions required for maintaining and operating an acceptable radiation protection program for the public and the environment. It also contains guidance to help define how the performance criteria can be met and includes specific actions, equipment selections, and operational methods that would be expected to meet the performance requirements.

Liquid and airborne effluent monitoring is specifically addressed in Chapters 2 and 3, respectively. These chapters provide guidance regarding these particular process monitors.

Radiation monitoring systems consist of several different types. Included in this category are CAMs, ARMs, portable and fixed-location personnel monitors, process monitors, and criticality monitors.

Continuous Air Monitors (CAMs)

10 CFR 835.403(a)(1) requires air sampling in the workplace when, under typical conditions, an individual would be likely to receive an annual intake of 2 percent or more of the specified annual limit on intake (ALI) values. The 2 percent value equates to an annual dose equivalent of 100 mrem. To assist in satisfying this requirement, CAMs are routinely used at DOE facilities.

The overriding purpose for using CAMs is to detect the presence of airborne radioactivity. These devices are designed to continuously sample and measure the air for radioactivity. They provide real-time monitoring capability. Under 10 CFR 835.403(a)(2), real-time air monitoring must be performed in normally occupied areas for one or both of the following situations: where an individual is likely to be exposed to a concentration of airborne radioactivity exceeding one derived air concentration (DAC) for the radionuclide of interest or where there is a need to alert potentially exposed individuals to unexpected increases in airborne radioactivity levels.

At DOE facilities, the emphasis in the occupational setting is often devoted to detecting the presence of alpha-emitting transuranics such as plutonium, americium, etc. Beta CAMs are also used. If a preset exposure level is exceeded, possibly due to an unplanned release, modern CAMs are designed to activate an alarm system with the intent of reducing occupational exposures. CAMs should be designed to respond in the shortest possible time and at the lowest detectable level of radioactivity, keeping in mind the need to reduce, and preferably avoid, spurious alarms. Alarm capability and adequate sensitivity are requirements mandated in 10 CFR 835.403(a)(3).

Issues related to the use of CAMs include, but not limited to:

- Design features
- Appropriate placement locations
- Choice of filter media
- Particle size dependence
- Flow rate measurements
- The ever-present problem of dealing with the
- Presence of naturally-occurring airborne radioactivity

General Principle of Operation

CAMs basically function by employing a flow system to steadily draw air, containing radioactive particulates, gases, or vapors, into the monitor. Particulates are deposited on some sort of collection substrate. For alpha radioactivity measurements, solid state detectors (typically a surface barrier or diffused junction semiconductor) work in concert with a multichannel analyzer (MCA) to detect, record, identify the radionuclide(s) of interest, and analyze the energy distribution. Zinc sulfide (ZnS) scintillators are also used, but for detection purposes only.

Beta particulate CAMs primarily employ gas proportional counters and/or silicon surface barrier detectors to record radiation events. Air monitors utilizing beta (plastic) scintillators, Geiger-Muller (G-M) detectors, and ionization chambers are being phased out, principally because of problems associated with radon progeny rejection. Those monitors employing G-M detectors tend to be larger and heavier than other CAMs because of the shielding materials required to reduce the background radiation levels.

Radioactive gases and vapors containing beta emitters are primarily collected using proportional counters and beta scintillators. Ionization chambers have also been used, but only for tritium, a radioactive gas. The larger the chamber, the more sensitive the measurement becomes.

Most CAMs separate airborne particulates through the filtration process where a physical barrier (a filter) removes particulates from the air stream. To a lesser extent, the process of inertial impaction--the removal of particulates that due to their inertia cannot make a bend in the air stream and are therefore impacted--is used in some CAM designs. A diagram of an impactor system used at one DOE facility is illustrated at the end of this competency. Inertial impactors either deposit the particulates on a detector or on a collection substrate placed over the detector.

Types of CAMS

There are a variety of CAMs in use today. These include particulate CAMs, ionization chamber flow-through CAMs, impactor alpha CAMs, tritium CAMs, silicon-diffused alpha CAMs, and CAMs that utilize remote monitors. Silicon-diffused CAMs are more rugged than surface barrier detectors that can be attacked chemically, for example, by hydrofluoric acid (HF)--used at certain DOE uranium facilities during the enrichment process. Remote monitors offer the advantage of becoming part of a local area network, utilizing cable lines, telephone systems, or radio modems (telemetry) to transmit information back to a central processing unit. Modern CAMs are now microprocessor-based systems, which greatly adds to their flexibility in the occupational setting.

Design Features

Design features will vary depending on the type of CAM being used and the manufacturer of the device. A few illustrations of different CAM designs can be found at the end of this competency. Several representative design features for an alpha particulate CAM (common at DOE facilities, as noted previously) include:

- Solid state detector
- Readout display
- Multichannel analyzer
- Micro-computer technology
- Mass air flow measuring system

- Communication ports
- Calibration and alarm setting keypad inputs
- Audible and visual alarms
- Failure warning alarms
- Local/remote air intake locations
- Real time clock
- Battery backup
- Subtraction Function
- Miscellaneous: size, weight, temperature range, power requirements

Several general comments related to the above design features can be made. The detector is a semiconductor with a typical diameter and active area on the order of 25 mm and 490 mm^2, respectively. A variety of filter media are used including millipore, fluoropore, cellulose and glass fibers. Air is typically drawn into the gap between the detector and the filter. The filter and the detector are parallel to each other and separated by a distance of 5 to 7 mm. The readout display can supply a great deal of information such as time and date, flow rate, energy spectra, and measured values of count rate in counts per minute (cpm) and air concentrations (μCi/ml, Bq/m^3, etc.). Count rates on the order of one million cpm are possible. Some CAMs are equipped with strip chart recorders in selectable time units (e.g., seconds, hours). The MCA is equipped with 256 or more channels to allow measurements of specific alpha energies. The MCA has the capability of handling millions of counts per channel. Micro-computer technology has the inherent advantage of measurement and data storage capabilities. Historical files can be maintained on energy regions, volumes of air sampled, count and count rate determinations, and air concentrations. The air flow measuring system incorporates a mass flow determination that can be automatically included in air concentration calculations. Computer ports allow links between the CAM and other terminals/computers. A group of air monitors can be "networked" to a central computer. Output results can be printed for hard copy archiving. The local keypad requires a security access code, preventing inadvertent changes in operational settings. Alarms of an audible and visible nature are designed to actuate when alarm set points have been exceeded. Increases in the count rate, beyond what is expected or possibly statistical in nature, can trigger a high alarm. Failures related to the detector signal, loss of air flow, or the real time clock can result in a failure alarm. The subtraction function serves to minimize interferences from the naturally occurring radon and thoron progeny--a major point of interest when dealing with alpha CAMs. The success/failure of background subtraction techniques will influence the sensitivity of the air monitor. A sensitivity as low as 4 derived air concentration-hours (DAC-hrs) for Pu-239 with a typical radon-thoron background has been reported by equipment manufacturers.

DOE CAM Requirements/Recommendations

Requirements established by DOE under 10 CFR 835 regarding CAMs have been discussed previously. In addition, The DOE *Radiological Control Manual*, Chapter 5, contains several recommendations regarding their use (and that of other air monitoring devices). Article 551, in the DOE *Radiological Control Manual*, notes that radiological monitoring of airborne radioactivity should be conducted to characterize workplace conditions; to verify the effectiveness of physical design features, engineering controls, and administrative controls; and to identify areas requiring postings. In addition, Article 555 offers additional recommendations including:

- Air monitoring equipment should be used in situations where airborne radioactivity levels can fluctuate and early detection of airborne radioactivity could prevent or minimize inhalation of radioactivity by personnel. Selection of air monitoring equipment should be based on the specific job being monitored. Air monitoring equipment includes portable and fixed air sampling equipment and CAMs.
- CAM equipment should be installed in occupied areas where a person without respiratory protection is likely to be exposed to a concentration of radioactivity in air exceeding 1 DAC or where there is a need to alert potentially exposed workers to unexpected increases in the airborne radioactivity levels.

  NOTE: 10 CFR 835 does not mention "...without respiratory protection..."

- Air sampling equipment should be positioned, where possible, to measure air concentrations to which persons are exposed. Alternative methods must be used when this cannot be accomplished.
- Air monitoring equipment shall be routinely calibrated and maintained at least once per year. CAMs should be capable of measuring one DAC when averaged over 8 hours (8 DAC-hrs) under laboratory conditions.

  NOTE: The statement concerning the 8 DAC-hrs requirement does not appear in 10 CFR 835.

- CAM equipment required by Article 555.3 should have alarm capability and sufficient sensitivity to alert personnel that immediate action is necessary in order to minimize or terminate inhalation exposures.
- The proper operation of CAM equipment should be verified daily by performing an operational check. Operational checks should include positive air-flow indication, non-zero response to background activity, and internal check sources or 60 Hz electronic checks when available. CAM equipment operation should be verified weekly by checking for instrument response with a check source or with ambient levels of radon and thoron daughters.

CAM Location/Placement

In general, CAMs should be located where radioactive materials are stored in order to warn occupational workers of elevated airborne levels of radioactivity that could/do exceed administrative or regulatory limits. From a practical standpoint, proper placement requires a detailed, working knowledge of ventilation patterns and operating experience.

The issue of proper CAM placement is a serious one. In August 1993, DOE conducted a review of five contractor sites to evaluate concerns raised relative to alpha CAM performance. A team of experts examined airborne contamination data and alarm logs and determined that the CAMs alarmed only 15 to 30% of the time when an elevated airborne contamination level existed. The highest alarming percentage was disappointing, considering a room air contamination level of several hundred DAC-hrs was present. Inadequate placement of the CAM was considered the probable cause of these results. Alarm capability improved when air concentrations exhibited little variability across the room, that is, when the distribution of air was uniform. In contrast, when localized spills occurred, even at activity levels mentioned above, the alarm rate worsened. The team also concluded that existing methodologies for determining the proper placement of a CAM were inadequate.

In addition, the issue of the validity of conventional methods for assessing the movement of particulates in an airstream, such as a smoke test, was raised. Certain contaminants, such as plutonium, have particle sizes that do not compare favorably with that of smoke particulates. Using commonly performed airflow studies to determine the proper placement of a CAM may be simply inappropriate. The Inhalation Toxicology Research Institute (ITRI) has experimented with a generator that produces a wax aerosol containing a fluorescent dye. The aerosol has aerodynamic properties similar to alpha particles; the dye allows visual observation of the airflow patterns. Similar research in Oak Ridge, Tennessee, has focused on titanium dioxide. However, DOE has reservations, as to whether these studies will be beneficial from a practical point of view.

A CAM should preferably be placed in close proximity to a job location where the potential for airborne contamination is high. However, because of their size and expense, CAMs often end up located near room air exhaust points; the air sampled here cannot in most cases be considered representative of a worker's breathing zone. In fact, studies have shown that there can be a wide variability in air sampling results obtained from CAMs and samplers located much closer to the worker. With that in mind, remote monitors could be used to minimize worker distraction. For example, the latest generation of CAMs contain microprocessor chips attached to the sampling head/device. Each chip has its own individual address and information from that particular sampling unit is sent back to a central processing unit. Software driven programs, already in existence today, allow for up to 250 remote locations. Some of these locations could include the worker's breathing zone.

At DOE facilities, the presence of transuranic materials (notably plutonium) is a concern due to inhalation hazards. As noted previously, continuous real-time monitoring is required when an individual could be exposed to airborne radioactivity concentrations exceeding the DAC for the radionuclide of interest. The CAM must be equipped with alarms and sufficient sensitivity to quickly alert potentially-exposed occupational workers that action is required to reduce or end an inhalation exposure.

The discussion above emphasizes that key parameters in CAM placement are the ability to (1) collect a representative sample--a sample representative of what the workers are breathing, and (2) warn individuals of high air concentrations. Other noble objectives include determining when airborne radioactivity areas exist and whether confinement or leakage of radioactivity has occurred. NUREG-1400 and NRC Regulatory Guide 8.25, both titled, *Air Sampling in the Workplace*, discuss these issues and offer realistic airflow pattern scenarios with the aim of having the reader develop an awareness of how proper CAM locations are determined.

CAM Limitations

CAMs are not perfect devices. Some of their limitations include the following:

- The response of the instrument may not be directly related to the level of contamination in the workplace. When this occurs, the problem may lie in the placement of the monitor as discussed above.
- Seldom alarm for small low-level spills, probably because of a lack of sensitivity and improper CAM placement. Though these findings are not a surprise, small spills are fairly common and could be a major source of collective dose to workers.

  NOTE: A "small" spill, according to a DOE audit team which has evaluated several DOE contractor facilities, has the potential to result in a 0.1 to 0.5 rem committed effective dose equivalent (CEDE).

- "Puff-type" releases, which are localized and settle out quickly, are not detected until 90% of the worker's inhalation uptake has occurred, according to recent DOE findings.
- They are not meant to be used to quantify routine doses. Other detection mechanisms, such as surveys, personnel monitoring, and the use of area contamination monitors, are used instead.
- They are rarely located in the worker's breathing zone.
- They are often unavailable for use. Common problems encountered include units that are unplugged, lack of air flow, microswitch failures, and detector failures.

Selection of Filter Media

CAMs employ a variety of filters. The filter is essentially a mechanical barrier that is designed to remove particulates of varying sizes out of the airstream. The decision to use a fibrous (e.g., cellulose or glass fiber), membrane filter (millipore), or combination membrane/fibrous filter (e.g., fluoropore), requires some study. Membrane filters are often referred to as surface loading filters because airborne particulates are collected on the surface of the filter. Fibrous filters, known as depth filters, trap particulates deeper within the matrix of the filter. This can be very important from a practical standpoint; if collection of alpha radioactivity is of interest, choosing a fibrous filter could promote significant self-absorption. Knowledge of that likelihood might necessitate the use of correction factors. The reader may wish to consult the ITRI for information related to filter media characteristics.

Alpha Spectra Considerations

The nature of alpha particle interactions with matter necessitates a consideration of various factors that could degrade an alpha spectrum. Degradation results in a larger full-width at half-maximum (FWHM) resulting in poorer resolution. This effect can be caused by increased dust loading on the filter, the source-to-detector distance, and the size of the source and the detector. The air gap between the source and the detector is typically on the order of 5 to 7 mm. A gap is required to allow particulates to enter and deposit on the filter. Increasing the gap leads to alpha energy attenuation and a subsequent increase in the FWHM. It also reduces the efficiency of the detector. Reducing the source-to-detector distance also has disadvantages, notably the loss of particulates on internal walls of the sampler located in the vicinity of the detector and filter, and non-uniformity of filter collection.

As far as relative sizes of the filter and the detector are concerned, a larger filter is advantageous in that it provides a reduced pressure drop with a concomitant increase in flow rate. An increased flow rate effectively results in the collection of a greater sample without the disadvantages of filter loading and self-absorption. However, a filter that is larger than the detector results in a reduced detector efficiency because the diameter of the filter extends beyond the diameter of the detector. A larger detector with an equivalent diameter to the filter could, of course, be purchased. Cost considerations (especially when dealing with a semiconductor) would then come into play, but could be offset by increased CAM sensitivity. In short, it is not only desirable to use a comparably sized filter and detector, but to make each as large as practical, considering the factors just described.

NOTE: Worthwhile data can also be obtained if the detector is larger than the filter, but not the other way around!

Uniformity/Nonuniformity of Filter Deposits

It is preferable to collect uniform deposits of airborne particulates on a filter. Failure to do so may lead to one of two scenarios: (1) an underestimation of the particle size concentration based on efficiency considerations discussed previously, or (2) an overestimation of the concentration if the particulates end up primarily located at the center of the filter.

Particle Size Influences

The reliable operation of a CAM is strongly influenced by the variety of particle sizes collected from the airstream. For example, CAMs which operate on the principle of inertial impaction fail when collecting particles of 0.5 µm or below in size. This is considered significant in certain situations. Larger particles have also been observed to rebound off the collection surface of these particular devices and/or cause the dislodging of particles previously collected. In the latter instance, greasing the collection substrate (typically a planchet) will minimize this effect, but correspondingly degrade the energy spectrum. In other types of CAMs, larger particulates may end up lost on internal walls of the sampler, creating a bias toward the collection of smaller particulates on the filter media.

McFarland et al., Health Physics, Vol. 62, have discussed the idea of establishing a performance criterion of 10 µm as the "cut point" for present day CAMs. This consideration developed a few years ago when the Environmental Protection Agency (EPA) established that 50% of the particles of this size penetrate to the tracheobronchial (T-B) region of the lung.

System Reliability

There are several characteristics that a reliable air monitoring system should possess. A fundamental trait of the system is that it provide consistent responses to levels of airborne radioactivity. The precision (reproducibility) of the measurement can often be of greater importance than the accuracy of the measurement. A case in point is the measurement of airborne plutonium in the workplace. Respect and subsequent reliance of workers on these air monitors develops only after these systems demonstrate that the number of spurious alarms are minimized and that they will actuate an alarm after detecting (in a consistent manner) the lower limit of detection (LLD) for the radionuclide of interest. Secondly, the reliability of a CAM will be tested due to everyday usage. It may have to tolerate a wide range of environmentally harsh conditions. Even under these conditions, it is desirable that CAMs remain relatively problem free for as long as possible (e.g., a few years). Lastly, adherence to a strong maintenance and calibration program is an absolute must to achieve the desired performance of the system over the long term.

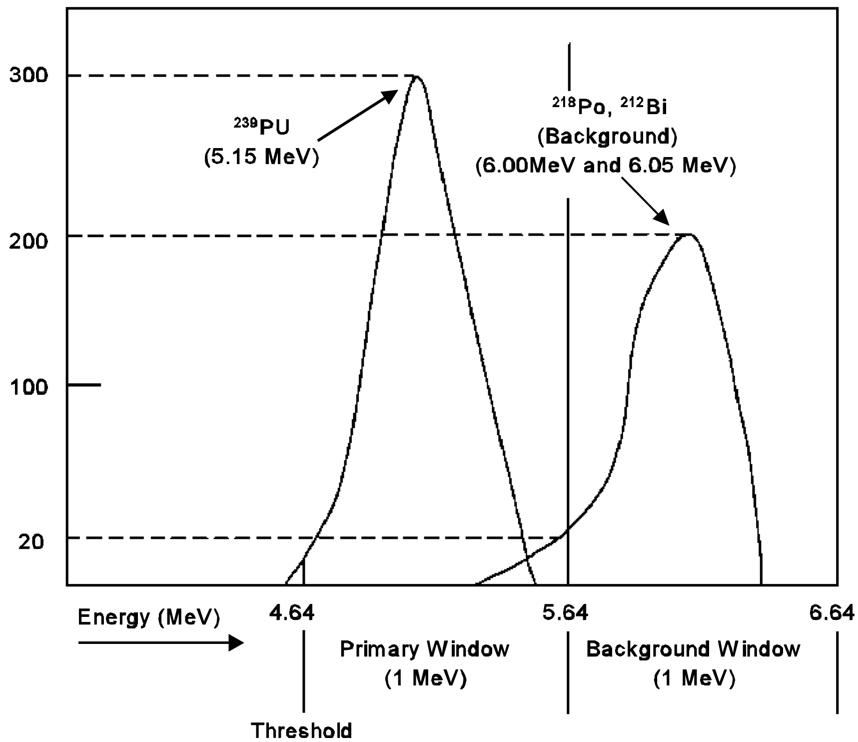
Discrimination Against Natural Airborne Radioactivity

One issue of concern in both the design and operational end of a CAM system is the presence of natural airborne radioactivity, principally composed of radon and thoron progeny. These radionuclides can contribute significantly to the background on a CAM system because they emit alpha and beta radiations--the same radiations looked for in the occupational setting. As noted earlier, the DOE *Radiological Control Manual* recommends that CAMs be capable of measuring one DAC when averaged over 8 hours under controlled laboratory conditions. Recall that this requirement was dropped altogether in 10 CFR 835.

At the Waste Isolation Pilot Project (WIPP) facility near Carlsbad, New Mexico, background aerosols are produced from surface dust which has either filtered through the ventilation system, been produced during mining operations, or exhausted from vehicle emissions. Salt dust, also containing background radon/thoron progeny, is produced, primarily through mining operations. These dusts load on the collection media degrade the alpha spectra and reduce the number of counts due to man-made radioactivity, while the background count rate tends to rise. The likelihood of a false alarm is increased. The dusty environment of the WIPP facility offers real challenges for those CAM instruments employing alpha spectroscopy.

The difficulty in discriminating natural radioactivity from that generated in the workplace occurs because the energies associated with alpha decay from radon and thoron daughter products are very similar to alpha energies generated by man-made processes. For example, one of the radon progeny, polonium-218 (Po-218), emits a 6.0 MeV alpha particle. Bismuth-212 (Bi-212), found in the thorium series, also decays by alpha emission with an energy of 6.05 MeV. Once self-absorption in the filter media and attenuation of energy caused by the air gap between the filter and the detector is taken into account, these alpha energies can overlap with other radionuclides of interest, most notably the radionuclides plutonium-239 (Pu-239 [5.15 MeV]), plutonium-238 (Pu-238 [5.50 MeV]), and americium-241 (Am-241 [5.49 MeV]).

Several different methods have been used to provide solutions to this problem. A common approach is to use a background compensation technique employing a numerical algorithm to subtract background counts from the energy region of interest. If the algorithm is successful, the sensitivity on the low end will be improved and consequently, the alarm rate will be reduced. Secondly, inertial impaction devices are used to remove the source of background interference by collecting the heavier man-made alpha emitters on a planchet by impaction while exhausting the much smaller sized radon/thoron progeny from the CAM. The planchet is also often removed periodically and counted after a sufficient period of time has passed to allow for decay of the shorter-lived materials; this type of information is useful in developing a historical database for the long-lived contaminant of interest. A third solution to this problem usually entails setting an "energy window", an electronic setting in the instrument, to minimize background influences. This approach is illustrated in the figure below. A single channel analyzer can be employed to first measure the Po-218 and Bi-212 levels and then electronically subtract them out from the rest of the spectrum. More recently, McFarland et al., Health Physics, Vol. 62, have experimented with a screen-type preseparator to remove radon/thoron daughters. The authors reported a removal efficiency of 99%. Each of these methods has its limitations, but is intended to improve the CAMs detection sensitivity and reduce the possibility of an inadvertent alarm to an acceptable level.



CAM Maintenance, Surveillance, and Calibration

Proper calibration and maintenance is essential to the continued reliability of an air monitoring system. To that end, maintenance and calibration programs must be developed. Proper maintenance and calibration of air monitors must be performed in accordance with applicable standards and regulations. ANSI N323-1978, *Radiation Protection Instrumentation Test and Calibration*, requires periodic performance testing and calibration. New equipment should be inspected and undergo acceptance testing upon receipt. A record of each instrument's maintenance history should be developed as a way to track system performance. Radiation check sources should be calibrated monthly. Calibration of the CAM should be performed using a documented procedure and qualified individuals. At DOE facilities, calibrations are typically performed on an annual basis. Quarterly calibration schedules are also used at some DOE facilities. In practice, there are significant differences in the complexity of calibration procedures at these facilities; procedures for the calibration of CAMs range from quite detailed (a variety of internal components are checked) to simple (signal-in signal-out tests). The CAM air flow measuring device, usually a simple rotameter, should be recalibrated at least annually.

CAM surveillance and testing includes items such as changing filter paper, conducting performance testing, visually inspecting the unit, calibration, and maintenance. Time frames for conducting these tasks can be as frequent as once each shift (for routine visual inspections) to as much as one year (calibration/maintenance procedures). Each facility determines how often these activities will be performed.

Recordkeeping and Occurrence Reporting

Documentation is useful and necessary for evaluating the performance of air monitoring instruments. Documentation covers a variety of areas related to CAMs including, system design and selection, data collected from the workplace, calibrations, system adjustments, procedural changes, etc.

In the DOE system, occurrence reporting is required under DOE Order 5000.3, *Occurrence Reporting and Processing of Operations Information* (first issued in May 1990). Any failure in the operation of a CAM is potentially subject to reporting through the DOE Occurrence Reporting and Processing System, otherwise known as "ORPS". However, DOE has discovered that differing interpretations of Order 5000.3 by its contractors lead to inconsistencies in reporting practices. For example, some DOE facilities report every CAM failure, while others only report failures that affect worker safety or involve work stoppages. Apparently, the performance of CAMs should not be based solely on reporting occurrences. Perhaps in part because of these differing interpretations, an update (DOE Order 5000.3B) to DOE Order 5000.3 and 5000.3A, was issued in January 1993.

Area Radiation Monitors (ARMs)

ARMs are utilized to control radiation exposures in a workplace setting. A variety of ARM systems exist. Emphasis is typically placed on the detection of gamma radiation intensities throughout the facility. To satisfy that objective, ARMs are either wall-mounted or operated as a free-standing unit in areas requiring monitoring. These devices tend to be fairly rugged and versatile, yet compact and lightweight. G-M or ionization chamber detectors are typically used. Depending on the detector, energy compensation is provided to allow a flat roentgen response versus gamma energy. Radiation levels ranging from 0.01 mR/hr up to 10,000 R/hr are typical. ARMs are designed to provide normal/fail indicators for safe operation; remote indicators are available which include meter, audible, and visual alarms. High radiation alarms and alarms designed to "alert" the worker that an alert level has been exceeded can be set over the entire meter range. Audible alarms often consist of a horn; visual alarms employ a light or beacon which may flash on and off depending on the design.

From a regulatory perspective, the use of stationary (area) or portable radiation instrumentation for the purpose of measuring ambient radiation dose rates is required under 10 CFR 835.403(b). The DOE *Radiological Control Manual* (Article 553) recommends that:

- ARMs should be:
  - installed in frequently occupied areas where the potential exists for unanticipated increases in dose rates.
  - also placed in remote locations where a need for local indication of dose rates prior to personnel entry exists.
  - used to measure only the radiation for which the calibration is valid.
  - tested at least quarterly to verify audible alarm system operability and audibility under ambient working conditions and operability of visual alarms when so equipped.
- The need and placement of an ARM should be documented and assessed when changes to facilities, systems, or equipment occur.
- Where an ARM is incorporated into a safety interlock system, the circuitry should be such that a failure of the monitor should either prevent entry into the area or prevent operation of the radiation producing device.
- ARMs should not be substituted for radiation exposure surveys in characterizing a workplace.
- If installed instrumentation is removed from service for maintenance or calibration, a radiation monitoring program providing at least equal detection capability should be maintained, consistent with the potential for unexpected increases in radiation dose rates.

Personnel Monitors

Personnel monitors are designed to determine the amount of radioactivity that might be present on personnel--in their excretions, on their skin, or any part of their clothing. 10 CFR 835, Subpart E, requires workplace monitoring. Section 835.401 lists the general requirements for workplace instrumentation including:

- The need for periodic maintenance and calibration
- The choice of appropriate instrumentation for the type(s), levels, and energies encountered
- Consideration of environmental conditions the instrument(s) would be exposed to
- Determination/confirmation of the operability of the instrument.

Section 835.404 addresses more specifically the requirements for radioactive contamination control and monitoring. The instrumentation selected must be able to satisfy the requirements of 10 CFR 835.

While the use of portable instrumentation is an important component of contamination control, this section emphasizes the use of fixed (stationary) personnel contamination monitors. These devices are typically designed to allow the user to place his/her hands and feet in the monitor ("hand and foot" monitors), wait for a sufficient period of time to achieve sufficient sensitivity and then inform the individual as to whether he/she is free of contamination. Visual and audible alarms are utilized to relay the contamination status to the individual. These monitors are meant to signal the presence of radioactivity, not necessarily the exact location. If contamination is found, portable radiological instrumentation can localize the area of contamination and facilitate decontamination procedures. Large area detectors are in use which allow the detection of contamination over a much larger area of the body.

Fixed personnel monitors primarily employ gas-flow proportional counters and fixed volume (gas-filled) G-M detectors to detect alpha, beta, and gamma radiation. Thin mylar windows are required to allow detection capability, especially in the case of alpha particles. In some cases, solid-filled scintillation detectors are used for detection of alpha radiation.

These monitors should be placed at strategic locations in the facility. Common locations include egress points from radiologically controlled areas where contamination could potentially exist. The number of monitors is influenced by the number of work stations and the locations where higher contamination levels are found.

Process Radiation Monitors

Process radiation monitors are designed to detect concentrations of liquid and gaseous radioactivity in work areas, stacks, ducts, laboratories, etc. A variety of these systems exist and are routinely used as indicators of both normal and abnormal system operating conditions. They may also provide an estimate of the quantity of radioactivity released to the environment.

DOE EH/0173T, *Environmental Regulatory Guide*, addresses liquid and gaseous effluent monitoring in Chapters 2 and 3, respectively. Both chapters are intended to assist each DOE-controlled facility meet the requirements of DOE Order 5400.1, *General Environmental Protection Program Requirements*, and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*.

Chapter 2 discusses general criteria and monitoring requirements, performance standards for liquid effluent monitoring systems, sampling and monitoring systems design criteria and considerations, alarm levels, and quality assurance.

Monitoring of liquid wastes should be performed to:

- demonstrate compliance with DOE Order 5400.5 (specifically Chapter 2)
- quantify radionuclides released from each discharge point
- alert appropriate personnel of "upsets" in processes and emissions controls

Continuous radionuclide monitoring is recommended for routine releases that could exceed one derived concentration guide (1 DCG) at the release point when averaged over one year or unanticipated releases exceeding 1 DCG averaged over one year. Continuous sampling combined with frequent analyses can substitute for continuous monitoring if emissions cannot be detected by technically current continuous monitoring devices. Appropriate statistical parameters should be considered to determine the accuracy of sampling results. The regulatory guide points out that the level of monitoring effort is determined by the importance of the sources during routine operations and the potential for accidental releases to the environment and dose to the general public.

Performance standards for a liquid effluent monitoring system are based on a careful characterization of several parameters. These include the source(s), pollutant(s), sample collection system(s), treatment system(s), and final release point(s) of the effluents.

If a facility is new or has been modified, a preoperational assessment is recommended to determine the impact on effluent release quantity, quality, and sensitivity of the monitoring or surveillance system. This assessment should be used to determine liquid effluent types and quantities, and facility monitoring needs. It is important that the system perform to a level that allows compliance with DOE Order 5400.5 (specifically, being able to detect radionuclide concentrations at or below the DCG in addition to meeting reporting requirements). Sufficient sensitivity regarding statistical detection levels is advocated.

Performance standards include consideration of continuous monitoring/sampling, sampling systems, calibration of monitoring and sampling systems, and environmental conditions.

Design criteria associated with liquid effluent systems exist to promote representative sampling. The following general criteria assist in meeting that objective:

- location for sampling and monitoring
- use of a highly reliable sampling pump where needed to provide uniform continuous flows
- redundant sampling collection systems or an appropriate alternative
- sampling ports located sufficiently downstream of the final feeder line to promote complete mixing
- sampling a proportional amount of the full effluent flow

- accuracies within ±10% regarding effluent streams and sample-line flows
- emphasis on maintaining structural integrity of the effluent sampling lines

Design considerations for the liquid effluent monitoring systems include the following:

- purpose - monitoring provides a prompt signal if a significant release occurs. Written procedures are advocated to document the actions that should be taken if an abnormal signal is detected. Both in-line and off-line monitoring may be required to accommodate routine and emergency monitoring.
- general design criteria - the type of radiation influence whether actual direct measurements or sampling and analysis is required (or a combination thereof). Alpha emitters and some beta emitters pose concerns from a measurement perspective; therefore, sampling and analysis should be performed to quantify releases associated with these radiations. Gamma radiation can usually be detected by direct measurement. Shielding may be required for high background areas. In these cases, off-line monitoring is encouraged. Grab samples can be utilized for "batch" releases where the concentration of radioactivity is constant, but the release is of short duration. When "continuous" effluent streams are present, continuous monitoring and/or sampling should be performed. Environmental conditions influence the design of the monitoring/sampling system. Air conditioning and heating provide reliable system operation to minimize worker exposures; background dose rates are considerations in accessing the system for calibration and servicing. Shielding should be considered when warranted.

Alarms are recommended to provide timely warnings and signal the need for corrective actions prior to a release exceeding the limits or recommendations in Order 5400.5. The collection of a variety of samples (grab, continuous, or proportional) is encouraged to detect the levels of radioactivity before significant impacts on the public or the environment occur.

General quality assurance (QA) provisions are contained in Chapter 10 of the regulatory guide. Specific requirements should be detailed in a facility/site specific QA plan.

Four basic sampling alternatives are noted in the regulatory guide:

- off-line periodic - grab samples of waste streams are taken on a periodic basis, concentrated (if needed), and delivered to the laboratory.
- off-line sequential - time aliquots of the effluent are taken when a relatively constant waste stream flow rate is present.
- off-line proportional - known fractions of the effluent are collected on a continuous basis prior to laboratory analysis.
- off-line continuous - samples are continuously collected at a known, uniform rate

In the laboratory, the presence of alpha, beta, and gamma radioactivity in liquid effluents can be determined in different ways. For example, the sample can be placed in a stainless steel vessel holding approximately 20 to 25 liters of water. Various detectors are utilized to detect the radioactivity. Alpha and beta radiations, for instance, can be detected using proportional or liquid scintillation counters while gamma radiation is detected with sodium iodide (NaI) scintillators. These monitors tend to be quite heavy, often weighing on the order of 2,000 to 3,000 pounds.

Chapter 3 of the DOE *Environmental Regulatory Guide* is devoted to airborne effluent monitoring. This chapter begins by stating that airborne emissions from a DOE-controlled facility should be evaluated and assessments made of the potential for release of radioactivity.

This assessment is important in that it directly impacts the preparation of the site's effluent monitoring and environmental monitoring programs (discussed in DOE Orders 5400.1 and 5400.5, respectively).

The regulatory guide recommends that airborne emissions, having the potential for causing doses exceeding 0.1 mrem effective dose equivalent (EDE) to a member of the general public (under a realistic scenario) for emissions in a year, should be monitored. Chapter 3 describes various aspects of airborne effluent monitoring. These include general criteria and monitoring requirements, requirements for compliance with EPA regulations, performance standards for air sampling systems, design criteria for system components, point-source design criteria, alarm levels, and QA.

The following table, taken from the regulatory guide, lists the criteria for establishing an airborne emission monitoring program. The scope of the monitoring effort is dependent on the impact of the sources and the potential for accidental releases.

Criteria for Emission Monitoring	
Calculated Maximum Dose from Emissions in a Year to Members of the Public: H_E mrem [effective dose equivalent (EDE)]	Minimum Emission Monitoring Criteria*
$H_E \geq 1$	1. Continuously monitor emission points that could contribute $\geq$0.1 mrem in a year 2. Identify radionuclides that contribute $\geq$10% of the dose 3. Determine accuracy of results (±% accuracy and % confidence level) 4. Conduct a confirmatory environmental survey annually or Monitor at the receptor: 1. Continuously sample air at receptor 2. Collect and measure radionuclides contributing $\geq$1 mrem (EDE) above background 3. Establish sampler density sufficient to estimate dose to critical receptor given typical variability of meteorological conditions 4. Obtain prior approval from EPA
$0.1 < H_E < 1$	1. Continuously monitor emission points that could contribute $\geq$0.1 mrem in a year 2. Identify radionuclides that contribute 10% or more of the dose 3. Conduct confirmatory effluent monitoring at emission points where possible 4. Conduct a confirmatory environmental survey every few years
$H_E < 0.1$	1. Take periodic confirmatory measurements 2. Test to determine need to monitor by calculating dose (H_E) for normal operation, assuming that the emission controls are inoperative 3. Conduct a confirmatory environmental survey at least every five years

*Alternative criteria may be obtained through EH following coordination with EPA.

DOE-controlled facilities are subject to requirements put forth by the Environmental Protection Agency (EPA). Regarding air emissions, the two main regulations of interest are:

- 40 CFR 61, *National Emission Standards for Hazardous Air Pollutants*. The specific emission standard of 10 mrem is found in Subpart H of this regulation.
- 40 CFR 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*

The frequency for conducting continuous monitoring and/or sampling is stated in the previous table. Other performance parameters track very closely with those discussed under liquid effluent monitoring. This particular section differentiates the manner in which airborne emissions can occur, that is, "point" versus "diffuse" sources. Point sources imply a release from a single defined point (a vent or stack are typical examples). Diffuse sources cover much larger areas. Examples include ponds, contaminated areas, and structures without ventilation or with ventilation that does not have a well-defined release point. Diffuse sources, by their nature, receive significant attention in terms of their impact on public dose and the environment. The regulatory guide recommends that these sources be identified and assessed. Further, diffuse sources contributing a significant fraction of the public dose should not only be identified and assessed, but documented and verified annually.

The quantification of airborne emissions through the use of sampling and monitoring systems relies on such factors as timeliness, representative sampling, and adequate sensitivity. Characterizing and documenting sources of emissions requires consideration of several factors.

These include the identification of:

- actual or potential radionuclides by type and concentration
- fallout and naturally-occurring radionuclides
- materials of a biological or chemical nature that negatively impact on the goals of the sampling and monitoring program
- internal and external conditions such as environmental conditions, factors which lead to a complete loss of the system, and gas-stream characteristics

This section of the regulatory guide offers extensive information on design criteria for "point" emission sources. Furthermore, several important references are noted to assist responsible individuals at DOE facilities with implementing these criteria. Each subsection under this topic is listed in the following table along with cited references. The reader is encouraged to consult these additional sources of information.

Point Source Design Criteria (Subsection Heading)	Reference(s)
Gas-stream Characterization Methods (3.5.1)	EPA Methods 1,2,4; ASTM Annual Book of ASTM Standards (1985)
Location of Sample Extraction Sites (3.5.2)	EPA Method 1; ANSI N13.1-1969
Sample-Extraction Probes (3.5.3)	EPA Method 5; ANSI N13.1-1969
Sample Transport Lines (3.5.4)	EPA Method 5; ANSI N13.1-1969
Air Moving Systems (3.5.5)	Not Applicable
Air Flow Measurements (3.5.6)	DOE/EP-0096; ANSI N13.1-1969
Sample Collectors (3.5.7)	ANSI N13.1-1969
Continuous Monitoring Systems (3.5.8)	ANSI N42.18-1974 (R 1980); DOE/EP-0096; ANSI N317-1980

Several types of instrumentation are utilized at DOE facilities for the measurement of specific radionuclides. These include tritium monitors, ionization chambers (for gaseous tritium), radioiodine monitors, noble gas monitors, gross alpha and beta monitors, transuranic radionuclide monitors, uranium monitors, and particulate fission and activation product monitors. Each of these monitors have their own design features and capabilities.

Some of these process monitors are typically placed near stacks and ducts. Representative design features for these locations include:

- self-containment
- background subtraction
- noble gas compensation
- continuous readout displays
- several alarm functions (including normal, fail, alert, and high), audible alarms, e.g., a horn, and visual alarms such as a rotating beacon
- a pump (usually self-regulated)
- flow rate and pressure indicators.

One disadvantage of these systems is their weight. Due to shielding requirements, these systems often weigh on the order of several hundred pounds. Several different detectors are used depending on the application. For example, radioiodine monitors typically employ a sodium iodide [NaI(Tl)] scintillator.

Particulate beta emitters, radioactive iodine, and noble gases can be simultaneously collected using a PING (Particulate Iodine Noble Gas) monitor. These self-contained, cart-mounted systems are often placed near stacks and ducts for the purpose of providing effluent monitoring. The system is designed to remove the particulate fraction through the use of a filter, remove the iodine component using activated charcoal (or silver zeolite) cartridges, and finally the noble gas contribution by collecting a specified volume. PING systems utilize inorganic NaI scintillators for the presence of gamma radiation and organic (plastic) scintillators or energy compensated G-M detectors for beta radiation. To subtract the interfering radon progeny contribution, solid-state alpha detectors can be used. As with most process monitors, they are not easily transportable.

The purpose of nuclear criticality accident alarms and alarm systems is to alert personnel to promptly evacuate the area to reduce the risk of exposure to radiation. Generally, the nuclear criticality accident alarm system is meant to prevent large exposures to many people.

A nuclear criticality accident occurs without advance warning. There are no discernible indications that the accident is about to happen. Therefore, nuclear criticality accident alarm systems are "after-the-fact" alarms. Generally, the alarm will sound about a half a second after the criticality has occurred.

ANSI/ANS-8.3-1986, *Criticality Accident Alarm System*, addresses not only the need for alarm systems, but also describes the characteristics of alarm signals, dependability, testing procedures, and emergency planning. The specifications for alarm signals include recommended sound pressure levels and activation mechanisms that do not depend on human action.

The standard also provides guidance on the criteria for system design including:

- Reliability
- Vulnerability
- Seismic Tolerance
- Failure Warning
- Response Time
- Detection Criterion
- Sensitivity
- Spacing

Criticality alarm systems are generally composed of neutron or gamma radiation detectors and annunciation (signal) equipment. In addition, administrative procedures are needed to ensure that the equipment is maintained and properly calibrated.

As stated in ANSI/ANS-8.3, "Criticality alarm systems shall be designed to detect immediately the minimum accident of concern. For this purpose, in areas where material is handled or processes with only nominal shielding, the minimum accident of concern may be assumed to deliver the equivalent of an absorbed dose in free air of 20 rad at a distance of 2 meters from the reacting material within 60 seconds." Therefore, the minimum accident of concern assumption determines the alarm set point and the detector spacing in a work area.

The selection of the detector will generally be determined by the fissile material being used and the type of radiation emitted in the event of a criticality accident. Some facilities can accidentally produce gamma fluxes capable of setting off a criticality alarm without actually having a criticality. This situation would produce false alarms; therefore, a neutron detector would more likely be used instead of a gamma detector.

Lithium-6 (Li-6) used in combination with other elements is an example of a neutron detector. G-M detectors and NaI detectors could be used to detect gamma radiation.

The basic principle of operation is described in the following example.

Detector Type: zinc sulfide/lithium-6 (ZnS / ^{6}Li) doped neutron scintillator

- A polyethylene moderator is used to enhance neutron capture.
- Neutron capture by Li-6 produces α particles.
- The reaction of ZnS and α produces visible light photons.
- Light pulses are detected by a photomultiplier tube (PMT) producing electric signals proportional to the neutron flux.

Criticality accident alarms and alarm systems generally have built-in signals that indicate a malfunction or loss of power. These signals may be visible, audible, or both. Some alarms have built-in battery backup systems with battery chargers.

The alarms and alarm systems are tested periodically to ensure that:

- The system is operating within the design specifications, especially following modification or repair, including maintenance of redundancy.
- The system responds to radiation as designed.
- The evacuation signal is audible above background noise. This signal must be discernible as an evacuation alarm.
- Test results are recorded and maintained for each system.

3. Self-Study Scenarios/Activities and Solutions

Review

- 10 CFR 835, *Occupational Radiation Protection*
- DOE/EH-0256T, *Radiological Control Manual*
- DOE G-10 CFR 835/E2 (Revision 1), *Workplace Air Monitoring* (implementation guide)
- DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*
- ANSI/ANS-8.3-1986, *Criticality Accident Alarm Systems*

Actions or situations were combined to create new incidents for the following scenarios from these references:

- *Operating Experience Weekly Summary 96-24*, June 7 - 13, 1996, Event Number 1.
- *Operating Experience Weekly Summary 96-25*, June 14 - 20, 1996, Event Number 1.

Activity 1

During a routine test of the criticality alarm system, a DOE employee discovered that several of the facilities' audible alarms did not actuate. The employee found that wiring to the alarms had been accidentally broken while other electrical cables were being pulled through the cable run that contained criticality alarm wiring. The facilities' system provided indication, prior to the next scheduled test, that some of the audible alarms had been disabled.

Does the situation described above indicate compliance or non-compliance with the ANSI Standard?(Criteria for System Design [ANSI/ANS 8.3-1986, Section 5], Testing [ANSI/ANS 8.3-1986, Section 6]). Specify the evidence you have to support your conclusion. What lessons can be learned from this situation?

Your Solution:

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Activity 1, Solution
(Any reasonable paraphrase of the following is acceptable.)

The situation described above indicates compliance with the ANSI standard. Routine tests were performed and the system provided indication of disabled audible alarms. This situation underscores the importance of problem indicators and the importance of conducting routine tests.

Activity 2

Engineering drawings describing modifications at a DOE facility specified removal of "heat (radiation) detectors." Facility review of the modification package did not recognize that it included removal, rather than relocation, of criticality alarm system detectors. When the specified detectors were removed, no alarm was generated at the system monitoring panel. Subsequent investigation disclosed that the alarm panel was wired in such a way that, although a "failure" light was activated at an intermediate panel (an unmanned location), a loss of power/loss of detector signal was not generated at the monitoring panel in a normally manned area.

Does the situation described above indicate compliance or non-compliance with the ANSI Standard? (Criteria for System Design [ANSI/ANS 8.3-1986, Section 5] General Principles (ANSI/ANS 8.3-1986, Section 4]). Specify the evidence you have to support your conclusion. What lessons can be learned from this situation?

Your Solution:

Activity 2, Solution
(Any reasonable paraphrase of the following is acceptable.)

The situation described above indicates non-compliance with the ANSI standard. No alarm was present at the monitoring panel upon the removal of the detectors. In addition, the alarm panel was not correctly wired to ensure activation at a manned location. Also, loss of power would not have been noticed at the manned location. Lessons learned include the following:

- modifications to areas requiring criticality accident alarms should be carefully reviewed
- failure lights or indicators must be activated in manned areas
- the design did not consider double contingency implications
- the safety review committee should pay more attention to what they are reviewing
- safety systems need special attention

Activity 3

A DOE facility experienced an activation of the plant's criticality alarm system, but no criticality had actually occurred. Investigation found that the alarm had been generated when the uninterruptible power supply (UPS) circuit that powered the alarm system was turned off by means of a switch in the facility's main computer room. The switch had been backfitted to the system to allow for cutoff of all power to the computer room in emergency situations and was not intended to affect power to the criticality alarm system. The modification review associated with the addition of the switch did not identify the fact that the planned location was between the UPS source and the primary criticality alarm system circuit.

Does the situation described above indicate compliance or non-compliance with the ANSI Standard? (General Principles [ANSI/ANS 8.3-1986, Section],Testing [ANSI/ANS 8.3-1986, Section 6]). Specify the evidence you have to support your conclusion. What lessons can be learned from this situation?

Your Solution:

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Activity 3, Solution
(Any reasonable paraphrase of the following is acceptable.)

The situation described above indicates non-compliance with the ANSI standard. Loss of power resulted in a false alarm. In addition, there was no apparent testing of the system after the modification. Lessons learned include the importance of a modification review specifying criticality accident alarm concerns and the importance of testing following modifications.

Activity 4

During an electrical storm, the criticality safety alarms at only the DOE facility's waste treatment facility sounded because of a momentary power interruption. Personnel in the building did not evacuate, but instead called security, who in turn notified appropriate radiological control and electrical shop personnel. The electricians arrived at the building to silence the alarms without receiving clearance to do so. They entered the waste treatment facility and silenced the alarms.

Does the situation described above indicate compliance or non-compliance with the ANSI Standard? (General Principles [ANSI/ANS 8.3-1986, Section 4]). Specify the evidence you have to support your conclusion. What can be inferred from the personnel response in this case? What lessons can be learned from this situation?

Your Solution:

Activity 4, Solution
(Any reasonable paraphrase of the following is acceptable.)

The situation described above indicates non-compliance with the ANSI standard. A false alarm resulted from the momentary loss of power. Personnel do not always follow procedures. Frequent false alarms lessen the response of personnel to potential emergency situations. Personnel may need to be "overtrained" to respond to emergency alarms. The main lesson is that it is very important to have battery backup to avoid false alarms.

Activity 5

A test of a building's criticality alarm system was in progress when facility personnel found a subcontractor security inspector inside the building. During such tests, all unnecessary personnel were evacuated from the building and the entrance doors were locked to prevent entry. Flashing criticality warning beacons, mounted outside each entrance, were also activated during the surveillance test. Permanently posted instructions at each entrance warned people not to enter the building when the beacon is operating. The security inspector had entered the building using his security key, despite the flashing warning beacon and the written instructions. His action constituted a breach of administrative controls specified in the criticality alarm test procedure.
A lack of training was not considered to be at issue in this event.

Does the situation described above indicate compliance or non-compliance with the ANSI Standard? (Testing [ANSI/ANS 8.3-1986, Section 6], Employee Familiarization [ANSI/ANS 8.3-1986, Section 7]). Specify the evidence you have to support your conclusion. What lessons can be learned from this situation?

Your Solution:

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Activity 5, Solution
(Any reasonable paraphrase of the following is acceptable.)

The situation described above indicates compliance by the facility. Compliance occurred because tests were being conducted and signs were permanently posted. Lessons learned include, some people do not believe the rules apply to them. Also, the severity of the consequences of not following procedures need to be emphasized.

4. Suggested Additional Readings and/or Courses

<u>Readings</u>

- Argonne National Laboratory. (1988). *Department of Energy Operational Health Physics Training* (ANL-88-26). Argonne, IL: Author.
- Cember, Herman (1996). *Introduction to Health Physics* (3rd ed.). McGraw-Hill: New York.

<u>Courses</u>
NOTE: See Appendix B for additional course information

- *Nuclear Physics/Radiation Monitoring* -- DOE
- DOE/EH-0450 (Revision 0), *Radiological Assessors Training (for Auditors and Inspectors) - Applied Radiological Control,* sponsored by the Office of Defense Programs, DOE
- *Applied Health Physics* -- Oak Ridge Institute for Science and Education
- *Health Physics for the Industrial Hygienist* -- Oak Ridge Institute for Science and Education
- *Safe Use of Radionuclides* -- Oak Ridge Institute for Science and Education
- *Radiation Protection Functional Area Qualification Standard Training* -- GTS Duratek

NOTES: